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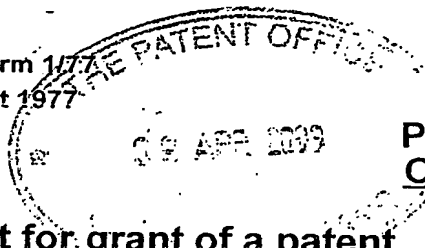
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1.	Your reference	
	1886402/DJBB	
2.	Patent Application Number	
	0308257.5	
3.	Full name, address and postcode of the or of each applicant(<u>underline all surnames</u>)	
	Sensopad Technologies Limited Harston Mill Harston Cambridgeshire CB2 5GG	
	Patents ADP number (if known)	8486003001
	If the applicant is a corporate body, give the country/state of its incorporation	Country: England State:
4.	Title of the invention	
	SENSING APPARATUS AND METHOD	
5.	Name of agent	
	Beresford & Co	
	"Address for Service" in the United Kingdom to which all correspondence should be sent	2/5 Warwick Court High Holborn London WC1R 5DH
	Patents ADP number	16 HIGH HOLBORN LONDON WC1V 6BX
6.	Priority details	
	Country	Priority application number
	UK	0224090.1
	Date of filing	16 October 2002

Patents Form 1/77

7. If this application is divided or otherwise derived from an earlier UK application give details

Number of earlier application

Date of filing

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Continuation sheets of this form

Description 20

Claim(s) 6

Abstract 1

Drawing(s) 6

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Statement of inventorship and right to grant of a patent (*Patents form 7/77*) 1 (+ 4 copies)

Request for preliminary examination and search (*Patents Form 9/77*) 1

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Date 9 April 2003

12. Name and daytime telephone number of person to contact in the United Kingdom

David BRINCK

Tel: 020 7831 2290

SENSING APPARATUS AND METHOD

This invention relates to a sensing apparatus and method,
in particular for sensing the relative position of two
members.

Various forms of inductive sensor have been used to
generate signals indicative of the position of two
relatively movable members. For example, UK Patent
Application No. 2374424 describes a position sensor in
which two excitation windings and a sensor winding are
formed on a first member, and a resonant circuit is
formed on a second member. The two excitation windings
are shaped so that the electromagnetic coupling between
the excitation windings and the resonant circuit varies
along a measurement path in accordance with a sine
function and a cosine function respectively. By applying
an in-phase oscillating signal and a quadrature
oscillating signal (that is 90° out of phase with the in-
phase oscillating signal) to the first and second
excitation windings respectively, an oscillating signal
is generated in the resonant circuit whose phase is
dependent upon the relative position between the first
and second members along the measurement path. The
oscillating signal in the resonant circuit in turn

induces an oscillating signal in the sensor winding whose phase is indicative of the relative position between the first and second members along the measurement path.

5 A problem with the position sensor described in GB 2374424A is that the drive circuitry which applies the quadrature pair of excitation signals to the two excitation windings is relatively complex.

10 According to an aspect of the invention, there is provided a position sensor in which a signal generator applies an excitation signal to an excitation winding formed on a first member, wherein the excitation winding is electromagnetically coupled to at least two resonant
15 circuits formed on a second member which are spaced from each other along a measurement path. The excitation windings are shaped so that the electromagnetic coupling between the excitation winding and each of the resonators varies along the measurement path. In this way, by
20 applying an excitation signal to the excitation winding, respective different signals are induced in the resonators which depend upon the relative position of the first and second members.

25 An exemplary embodiment of the present invention will now

be described with reference to the accompanying drawings in which:

Figure 1 schematically shows a perspective view of a position sensor;

5 Figure 2 schematically shows the main components of the position sensor illustrated in Figure 1;

Figure 3 schematically shows how the respective phases of signals induced in two resonant circuits which form part of the position sensor illustrated in Figure 1 vary with the frequency of a driving signal;

10

Figure 4 shows an unmodulated signal and a sensed signal generated by the sensor illustrated in Figure 1;

Figure 5 shows part of a signal that is sensed by a sensor winding, which forms part of the position sensor illustrated in Figure 1, after mixing with a second frequency;

15

Figure 6 shows part of the signal illustrated in Figure 7 after filtering, together with a reference signal; and

20 Figure 7 is a schematic block diagram showing the main elements of the position sensor illustrated in Figure 1.

Figure 1 schematically shows a position sensor for detecting the position of a sensor element 1 which is

25

slidably mounted to a support (not shown) to allow linear movement along a measurement direction (the direction X in Figure 1). A printed circuit board (PCB) 3 extends along the measurement direction and has printed thereon conductive tracks which form a sine coil 5 and a sense coil 7, each of which are connected to a control unit 9. A display 11 is also connected to the control unit 9 for displaying a number representative of the position of the sensor element 1 in the measurement direction.

The sensor element 1 includes a printed circuit board 13 having conductive tracks printed thereon which form a first resonant circuit 15a and a second resonant circuit 15b which are spaced from each other in the measurement direction. By applying an excitation signal to the sine coil 3, resonant signals are induced in the two resonant circuits 15a, 15b on the sensor element 1, and these resonant signals in turn induce a signal in the sense coil 7 which is processed by the control unit 9 to determine the position of the sensor element 1 along the measurement direction.

As shown in Figure 1, the PCB 3 is generally rectangular in shape with the lengthwise axis aligned with the measurement direction and the widthwise axis aligned

perpendicular to the measurement direction. The sine coil 5 and the sense coil 7 are connected to the control unit 9 via a proximal lengthwise edge 17 of the PCB 3, and extend along the length of the PCB 3 to a distal lengthwise edge 19.

An overview of the operation of the position sensor illustrated in Figure 1 will now be given with reference to Figure 2. The control unit 9 includes an excitation signal generator 21 which generates an oscillating excitation signal having a frequency f_0 , which in this embodiment is 1MHz.

The excitation signal is applied to the sine coil 5 via the proximal lengthwise edge 17 of the PCB 3, which substantially corresponds to a position value of $x = 0$. The position value increases along the length of the PCB 3 from the proximal lengthwise edge 17 to the distal lengthwise edge 19, which substantially corresponds to a position value of $x = L$.

As shown in Figure 2, the sine coil 5 is formed by a conductive track which generally extends around the periphery of the PCB 3 apart from a cross-over point halfway along the PCB 3 in the measurement direction, at

which point the conductive track adjacent each widthwise edge of the PCB 3 crosses to the respective opposing widthwise edge of the PCB 3. In this way, effectively a first current loop 23a and a second current loop 23b are formed. When a signal is applied to the sine coil 5, current flows around the first current loop 23a and the second current loop 23b in opposite directions, and therefore the current flowing around the first current loop 23a generates a magnetic field which has an opposite polarity to the magnetic field generated by the current flow around the second current loop 23b.

The lay-out of the sine coil 5 is such that the field strength of the component of the magnetic field B resolved perpendicular to the PCB 3 which is generated by current flowing through the sine coil 5 varies along the measurement direction from approximately zero at the point where $x = 0$, then to a maximum value at $x = L/4$ (the position A as shown in Figure 1), then back to zero at $x = L/2$ (the position B as shown in Figure 1), then to a maximum value (having opposite polarity to the maximum at position A) at $x = 3L/4$, and then back to zero at $x = L$. In particular, the sine coil 3 generates a magnetic field component B perpendicular to the PCB 3 which varies according to one period of the sine

function, as set out in Equation 1,

$$B = A \sin\left(\frac{2\pi x}{L}\right) \quad (1)$$

where A is a constant.

5 When the excitation signal is applied to the sine coil
5, an oscillating signal at the same frequency is induced
in each of the two resonant circuits 15a, 15b on the
sensor element 1, with the magnitude of the induced
signal in each resonant circuit 15 being dependent upon
10 the strength of the magnetic field component B resolved
perpendicular to the PCB 3 at the respective position of
the resonant circuit 15 along the measurement direction.
In this embodiment, the first resonant circuit 15a is
separated from the second resonant circuit 15b by a
15 distance d which is equal to L/4, so that as the sensor
element 1 moves along the measurement direction the
magnitude of the resonant signals induced in the first
and second resonant circuits 15 vary in quadrature. A
phase lag is also introduced between the excitation
20 signal and the induced signal in each resonant circuit,
the amount of the phase lag being dependent upon the
relationship between the frequency of the excitation
signal and the resonant frequency of each resonant

circuit 15. Figure 3 shows the variation in phase lag with the frequency of the excitation signal for the first and second resonant circuits 15a, 15b. In particular, the curve referenced 31a shows the variation in phase lag with the frequency of the excitation signal for the first resonant circuit 15a, and the curve referenced 31b shows the variation in phase lag with the frequency of the excitation signal for the second resonant circuit 15b.

As shown in Figure 3, the resonant frequency f_{res}^1 of the first resonant circuit 15a is set so that at the frequency f_0 of the excitation signal, the phase lag of the induced signal in the first resonant circuit is $3\pi/4$, whereas the resonant frequency f_{res}^2 of the second resonant circuit 15b is set so that at the frequency f_0 of the excitation signal, the phase lag of the signal induced in the second resonant circuit is $\pi/4$. If the position of the first resonant circuit 15a along the measurement direction is X_0 , then the signals I_1 , I_2 induced in the first and second resonant circuits 15a, 15b are given by equations 2 and 3 respectively.

$$I_1 = B \sin\left(\frac{2\pi X_0}{L}\right) \cos\left(2\pi f_0 t - \frac{3\pi}{4}\right) \quad (2)$$

$$I_2 = B \sin \left(\frac{2\pi \left(X_0 + \frac{L}{4} \right)}{L} \right) \cos \left(2\pi f_0 t - \frac{\pi}{4} \right) \quad (3)$$

where B is a constant.

5

The induced signals I_1 , I_2 in turn induce a signal S in the sense coil 7 proportional to the sum of the induced signals I_1 and I_2 . This sum simplifies to the expression given in Equation 4, in which C is a constant.

$$S = C \cos \left(\frac{2\pi X_0}{L} - 2\pi f_0 t + \frac{\pi}{4} \right) \quad (4)$$

10

In effect, the phase of the signal S rotates as the sensor element 1 moves along the measurement direction.

15

As shown in Figure 2, the signal S is input to a timing comparator 25 which compares the timing of the signal S with the timing of a reference signal from the excitation signal generator 21 to determine a value representative of the phase of the signal S. This value is then input to a position calculator 27 which converts the value to

a position value for the sensor element 1, and outputs a drive signal to the display 11 causing the display 11 to show the position value.

5 As mentioned above, in this embodiment the frequency f_0 of the oscillating excitation signal is 1 MHz. This frequency is sufficiently high to induce a relatively large signal in each resonant circuit 15. Figure 4 shows the excitation signal P together with the signal S which
10 is induced in the sense coil 7. In Figure 6, the sense signal S has a phase delay of $0.1 \mu s$ with respect to the excitation signal P. At a frequency of 1 MHz, the phase delay will always be $1 \mu s$ or less, with the result that, in order to determine the position of the sensor element
15 accurately, it is necessary to resolve the phase delay to a value of 1 to $10 ns$, which is relatively difficult. If, however, the sensed signal S is mixed with a second signal of slightly lower or higher frequency, a signal as shown in Figure 5 is generated which contains a signal
20 at a frequency higher than the original signal, together with a lower frequency "beat" signal at a frequency equal to the frequency difference between the sensed signal and the second signal. This signal can be filtered to remove the high frequency signal and other signals and leave the
25 beat sinusoidal signal 35 as shown in Figure 6. The beat

signal 35 has a phase delay that is related to the position of the sensor element 1 so that it may be compared with a reference signal 37 of the same frequency to determine the position of the sensor element 1. It can be seen from Figure 6 that the phase delay of the resulting beat signal corresponds to much longer times with the result that relatively inexpensive circuitry can be employed to measure the phase delay.

Figure 7 schematically shows the circuitry within the control unit 9 in more detail, together with the sine coil 5 and sense coil 7. The circuitry within the control unit 9 comprises a microprocessor 41, signal generator 42, analogue driving circuitry 40 and analogue signal processing components 44.

The microprocessor 41 includes a square wave oscillator 112 which generates a square wave signal at twice the frequency f_0 (i.e. at 2 MHz). This square wave signal is output from the microprocessor 41 to the signal generator 42 which divides the square wave signal by two and forms an in-phase digital signal +I at the frequency f_0 . The in-phase signal +I is sent to the analogue driving circuitry 40, and is input to a coil driver 83 which amplifies the signal and outputs the excitation signal

to the sine coil 5.

5 The digital generation of the excitation signals applied to the sine coil 5 introduces high frequency harmonic noise. However, the coil driver 83 removes some of this high frequency harmonic noise, as does the frequency response characteristics of the sine coil 5. Further, the resonant circuits 15 within the sensor element 1 do not respond to signals which are greatly above their
10 respective resonant frequencies and therefore the resonant circuits 15 also filter out a portion of the unwanted high frequency harmonic noise.

15 The signal S induced in the sense coil 7 is passed through a high pass filter amplifier 93 which both amplifies the received signal, and removes low frequency noise (e.g. from a 50 Hz mains electricity supply) and any D.C. offset. The amplified signal is then input to a mixer 95, where the amplified signal is mixed with
20 a reference signal at a second frequency f_1 . The second signal of frequency f_1 is a digital signal having sinusoidal characteristics, and is generated by the signal generator 42. The second signal has a fundamental frequency somewhat higher or lower than that of the
25 original signals at frequency at f_0 so that the signal

output by the mixer 95 includes components at frequencies $f_0 + f_1$ and at $f_0 - f_1$. This mixed signal is then input to a low pass amplifier filter 97 to filter out the high frequency components, i.e. those components at a frequency of $f_0 + f_1$.

The second signal typically has a frequency f_1 that differs from f_0 by not more than 10% of the original frequency f_0 so that the components of the resulting signal have a frequency $f_0 - f_1$ which is at a much lower frequency than any other component of the signal and the higher frequency components can therefore easily be removed by means of an analogue filter. The filtered signal is then input to a band pass filter amplifier 99 having a pass band centred at $f_0 - f_1$, after which a generally sinusoidal third signal is formed as shown in Figure 6.

The signal output by the band pass filter amplifier 99 is input to a comparator 101 which converts it to a square wave signal whose rising and falling edges correspond with the zero crossing points of the sinusoidal signal of Figure 6. The square wave signal is input into a timer 104, forming part of the microprocessor 41, together with another square wave

signal V_{ref} , generated by the signal generator 42, of the same frequency which provides a reference phase.

5 The timer measures the difference between the timings of the rising and falling edges of the signal output by the comparator 101 and the reference signal V_{ref} , and outputs the measured timings to a processing unit 108 which determines the corresponding position value using a look-up table. The processing unit 108 then outputs the
10 determined position value to a display controller 110 which generates drive signals to cause the display 11 to show the determined position value.

15 Further details of the components and operation of the control unit 9 may be found in UK patent application no. 0224100.8, whose contents are hereby incorporated by reference.

MODIFICATIONS AND FURTHER EMBODIMENTS

20 In the illustrated embodiment, an excitation winding (i.e. the sine coil 5) is electromagnetically coupled to two resonators (i.e. the resonant circuits 15), and the resonant signals induced in the resonant circuits 15 are analysed using a sensor winding (i.e. the sense coil 7)
25 which is electromagnetically coupled with the two

resonators. It is not essential to use such a sensor winding because the resonant signals induced in the two resonators could be measured directly. Such direct measurement is not, however, preferred because it would require electrical connections to be made to the sensor element.

In the illustrated embodiment, the resonant circuits 15 on the sensor element 1 have overlapping, but not identical, ranges of frequencies over which a sinusoidal signal applied to the sine coil 5 induces a resonant signal in the sense coil 7. The frequency of the excitation signal is selected so that there is a quarter of a cycle phase difference between the signals induced in the first and second resonant circuits caused by the phase shifts which are inherent to resonators around the resonant frequency.

In an alternative embodiment, the resonant frequencies of the two resonant circuits 15 are spaced apart so that a single excitation frequency can not induce resonance in both resonant circuits. In this alternative embodiment, the excitation signal generator generates an excitation signal having two sinusoidal components, with each sinusoidal component inducing a resonant frequency

in a respective one of the two resonant circuits 15. In this way, a sensed signal is induced in the sense coil 7 having two frequency components matching the two frequency components of the excitation signal, and by measuring the relative strengths of the two frequency components in the sensed signal it is possible to determine the position of the sensor element 1. This removes the requirement for a specific phase shift to be present between the resonant signals induced in the first and second resonant circuits.

In the illustrated embodiment, the sensor element includes two resonant circuits 15 which are separated by a distance corresponding to a quarter of a cycle of the sine coil 5. This is not, however, essential as the sensor element could, for example, have two resonant circuits separated by three-quarters of a cycle of the sine coil 5. Alternatively, the sensor element could have three or more spaced resonant circuits.

In the illustrated embodiment, the sine coil 7 is arranged so that the magnetic field component perpendicular to the PCB 3 varies sinusoidally in accordance with position along the measurement direction, and the two resonant circuits are separated by a distance

of $L/4$ along the measurement direction. In this way, the electromagnetic coupling between the sine coil 5 and the first resonant circuit 15a varies in accordance with a first function (i.e. the sine function) and the electromagnetic coupling between the sine coil 5 and the second resonant circuit 15b varies in accordance with a second function (i.e. the cosine function). In order to achieve this, the sine coil has an alternate twisted loop structure. However, it would be apparent to a person skilled in the art that an enormous variety of different excitation winding geometries could be employed to form transmit aerials which achieve the objective of causing the relative strengths of the resonant signals appearing in the first and second resonant circuits to depend upon the position of the sensor element in the measurement direction according to respective first and second functions.

In the above described embodiment, a passive resonator is used. However, in some circumstances it may be advantageous to use a resonator including an amplifier so that the signal induced in the resonator is increased.

In the illustrated embodiment, instead of detecting the phase of the sense signal, it is also possible to perform

parallel synchronous detection of the sense signal, with one synchronous detection using an in-phase signal (with respect to the excitation signal) and the other synchronous detection using a quadrature signal (with respect to the excitation signal). By then performing an arctangent operation on the ratio of the magnitudes of the synchronously detected signals, a value representative of the position of the sensor element 1 in the measurement direction can be obtained.

10

In the described embodiment, the inductive sensor is used to measure the linear position of a first member (i.e. the sensor element 1) relative to a second member (i.e. the PCB 3) along a rectilinear measurement path.

15

Alternatively, the inductive sensor could be adapted to measure linear position along a curved measurement path, for example a circle (i.e. a rotary position sensor), by varying the layout of the sine coil in a manner which would be apparent to a person skilled in the art. The inductive sensor could also be used as a speed detector by taking a series of measurements of the position of the first member relative to the second member at known timings.

20

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In the illustrated embodiment, the sine coil, sense coil

and resonant circuits are formed by conductive tracks on a printed circuit board. Alternatively, a different planar substrate could be used. Further, the sine coil and sense coil could, if sufficiently rigid, be fixed relative to a first member and the resonant circuits fixed relative to a second member without the use of a substrate. It is also not essential that the sine coil, sense coil and resonant circuits are planar because, for example, cylindrical windings could also be used with the sensor element moving along the cylindrical axis of the cylindrical winding.

Of course, as the position sensor detects the relative position between first and second members, it does not matter which of the first member and the second member are moved, or even if both are moved.

In the above described embodiment, the excitation signal is a digital representation of a sinusoidal signal. This is not essential and may be convenient to use an excitation signal which is more easily generated. For example, the excitation signal could be a digital representation of a triangular waveform. The phase of the sensed signal can be decoded in the same way as the illustrated embodiment by only looking at the fundamental

frequency of the sensed signal, i.e. by filtering out the higher harmonics present in the triangular waveform. As described previously, the frequency responses of the analogue driving circuitry, the sine coil and the resonant circuits are effective in removing a large proportion of the higher harmonics.

CLAIMS

1. A position sensor comprising first and second members which are movable relative to each other along a measurement path, the first member comprising an excitation winding and the second member comprising first and second resonators spaced apart along the measurement path, wherein the excitation winding and the first resonator have a first electromagnetic coupling which varies with the relative position along the measurement path of the first and second members in accordance with a first function, and the excitation winding and the second resonator have a second electromagnetic coupling which varies with said relative position in accordance with a second function different from the first function;

an excitation signal generator operable to generate an excitation signal and to apply the excitation signal to the excitation winding to induce a first resonant signal in the first resonator and a second resonant signal in the second resonator; and

means for analysing the first and second resonant signals to determine a value representative of the relative position along the measurement path of the first and second members.

2. A position sensor according to claim 1, wherein said analysing means comprises a sensor winding electromagnetically coupled to the first and second resonators, wherein in response to the excitation signal being applied to the excitation winding, there is generated in the sensor winding an electric signal corresponding to a combination of the first and second resonant signals weighted in accordance with the relative position of the first and second members along the measurement path; and

a signal processor operable to process the electric signal generated in the sensor winding to determine a value representative of the relative position along the measurement path of the first and second members.

3. A position sensor according to claim 1 or 2, wherein the excitation winding and the first and second resonators are arranged so that said first and second functions vary sinusoidally with position with the same period but are out of phase with each other.

4. A position sensor according to claim 3, wherein the first and second functions are one quarter of a cycle out of phase with each other.

5. A position sensor according to any preceding claim, wherein the first resonator exhibits resonance in response to a first range of frequencies about a first resonant frequency and the second resonator exhibits resonance in response to a second range of frequencies about a second resonant frequency which is different from the first resonant frequency, the first and second ranges overlapping,

wherein the excitation generator is operable to generate an excitation signal having a frequency component which induces a resonant signal in the first resonator having a first phase shift and a resonant signal in the second resonator having a second phase shift which is different from the first phase shift.

6. A position sensor according to claim 5, wherein the first phase shift is different from the second phase shift by one quarter of a cycle.

7. A position sensor according to claim 6, wherein the analysing means is operable to measure a phase of a signal formed by a weighted combination of the first and second resonant signals.

8. A position sensor according to claim 7, wherein the analysing means is operable to generate a second signal at a frequency different from that of the excitation signal, and to mix the second signal with the signal
5 formed by a weighted combination of the first and second resonant signals to generate a third signal having a frequency component equal to the difference between the frequency of the excitation signal and that of the second signal, and to determine the said value from the phase
10 of the third signal.

9. A position sensor according to any preceding claim, wherein the first and second members are relatively movable along a rectilinear direction.

10. A position sensor according to any preceding claim, wherein the excitation winding is formed by a conductive track on a planar substrate.

11. A position sensor according to claim 10, wherein the planar substrate is a printed circuit board.

12. A position sensor according to either claim 10 or claim 11, wherein the excitation winding effectively comprises a plurality of loops arranged so that current flowing through the excitation winding flows around at least one of the loops in an opposite direction to at least one other of the loops.

13. A position sensor according to any preceding claim, wherein at least one of said first and second resonators comprises a passive resonant circuit.

14. A position sensor according to any of claims 1 to 12, wherein at least one of said first and second resonators comprises an amplifier for amplifying the power of a signal induced in the resonator.

15. A position sensor according to any preceding claim, wherein the first and second resonators comprise respective conductive tracks formed on a planar substrate.

16. A position sensor according to claim 15, wherein the planar substrate is a printed circuit board.

17. A position sensor according to any of claims 2 to 16, wherein the sensor winding is formed by a conductive track on a planar substrate.

5 18. A position sensor according to claim 17, wherein the sensor winding is formed on a printed circuit board.

19. A position sensor according to claim 17 or 18, wherein the sensor winding is formed in a single loop.

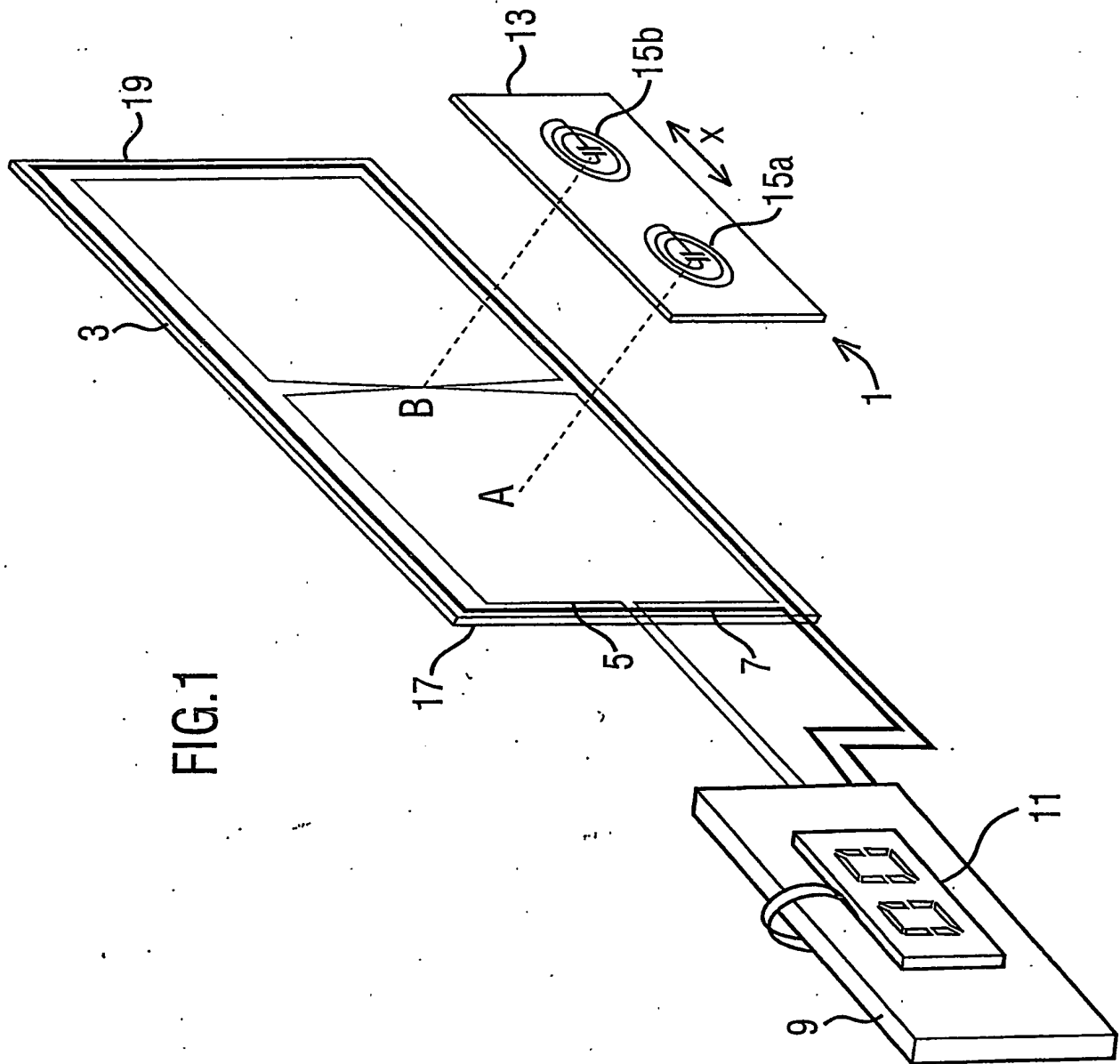
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20. A position sensor according to any preceding claim, wherein the excitation signal comprises a sinusoidal component at 1 MHz.

ABSTRACTSENSING APPARATUS AND METHOD

There is described an inductive position sensor in which
5 a signal generator applies a excitation signal to an
excitation winding formed on a first member, the
excitation winding being electromagnetically coupled to
at least two resonant circuits formed on a second member
which are spaced from each other along a measurement
10 path. The excitation windings are shaped so that the
electromagnetic coupling between the exciting winding and
each of the resonators varies along the measurement path.
In this way, by applying an excitation signal to the
excitation winding, respective different signals are
15 induced in the resonators which depend upon the relative
position of the first and second members.

Figure 2



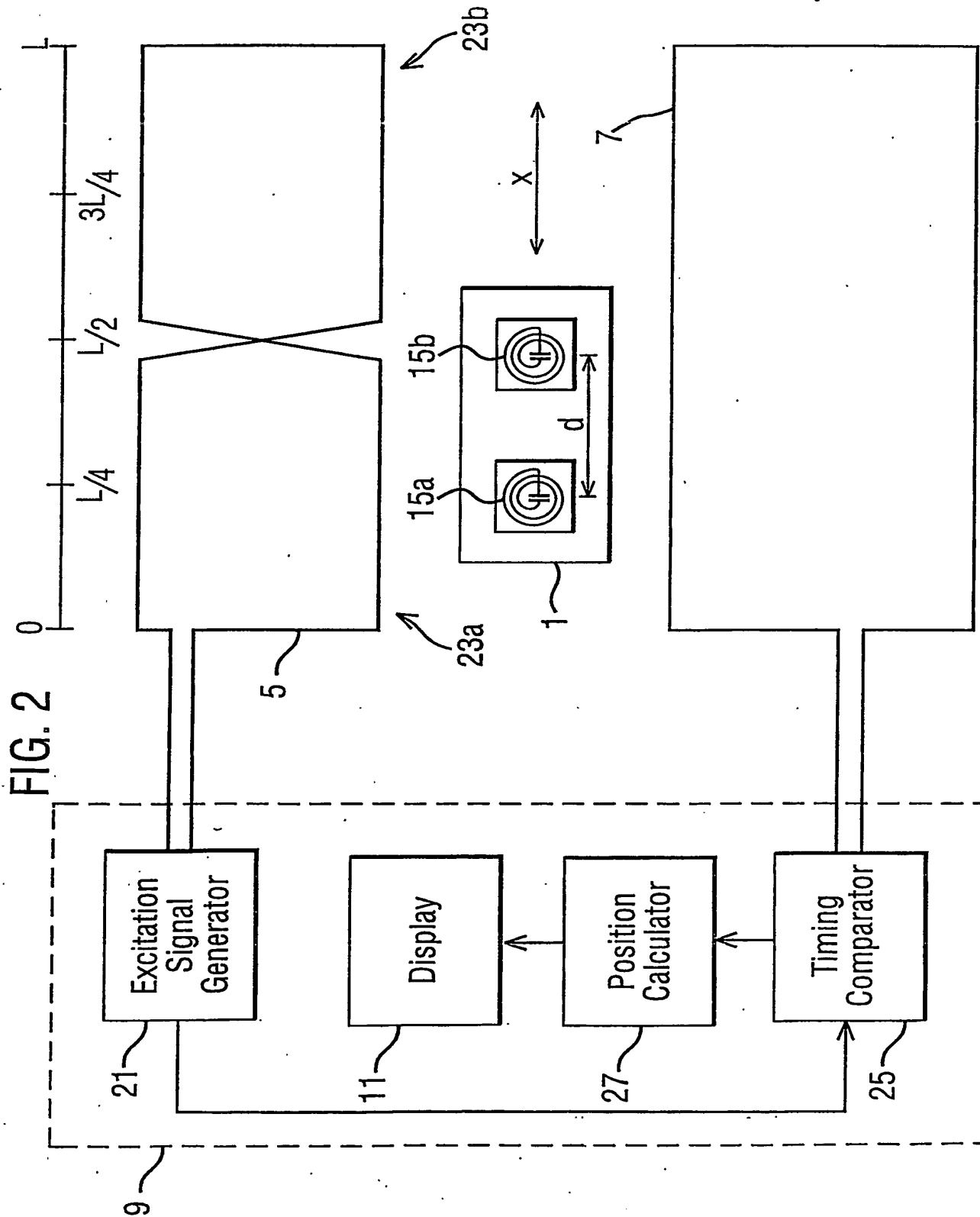


FIG. 3

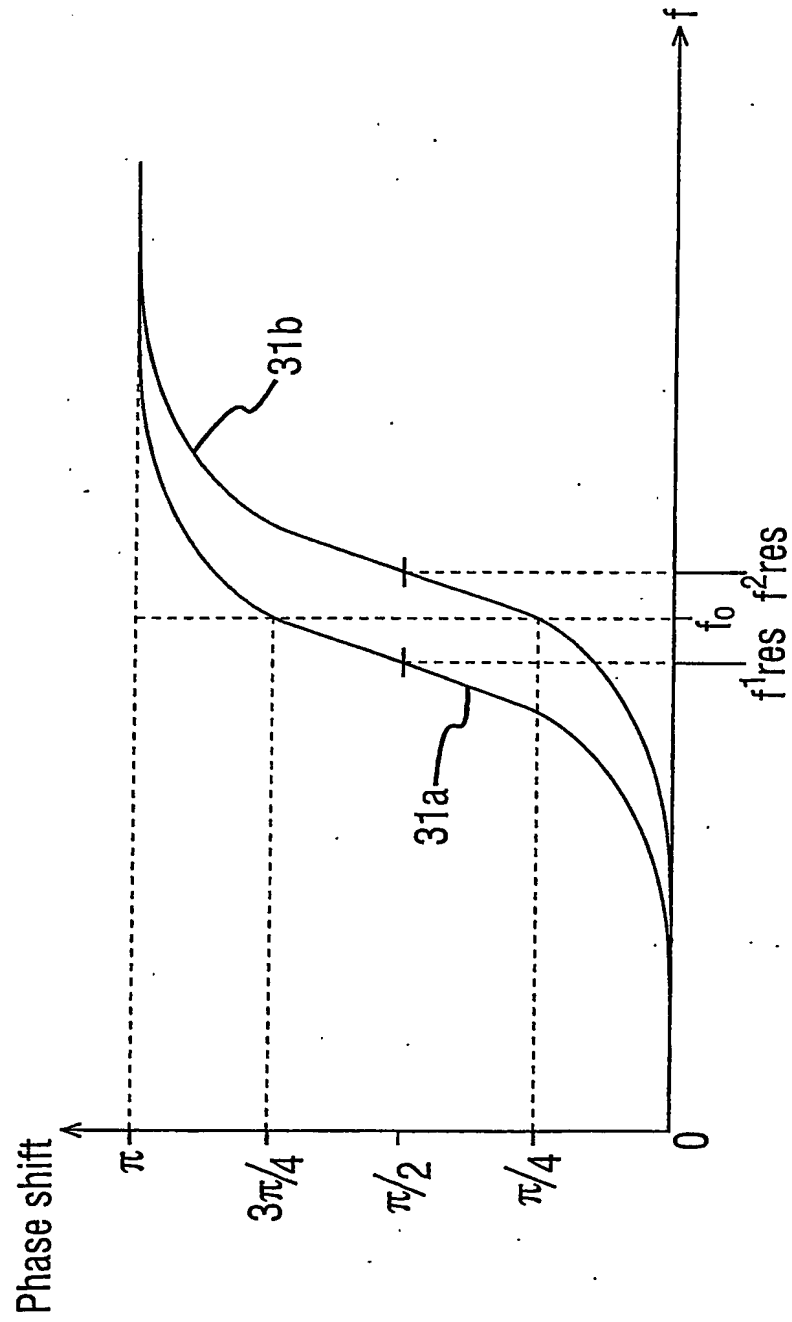


FIG. 4

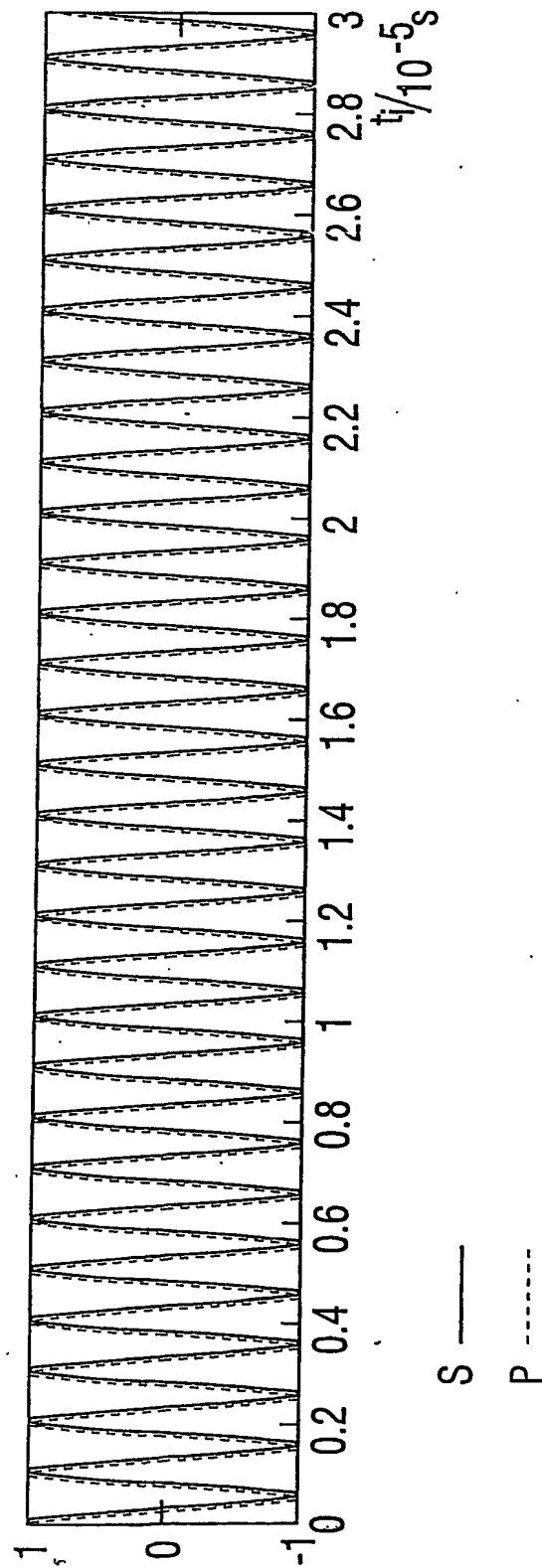


FIG. 5

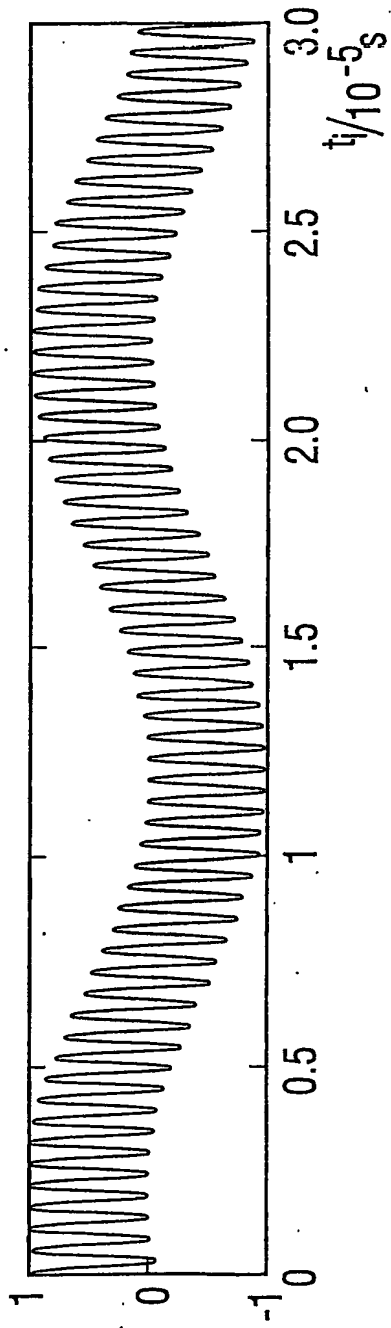


FIG. 6

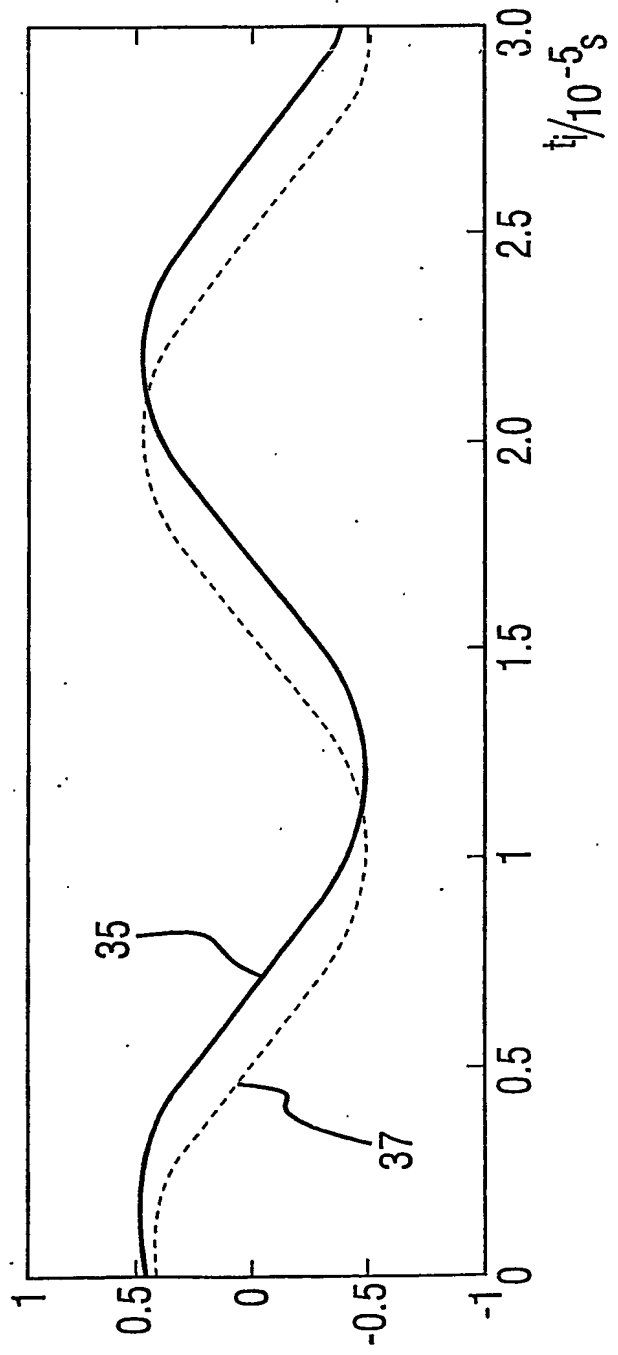
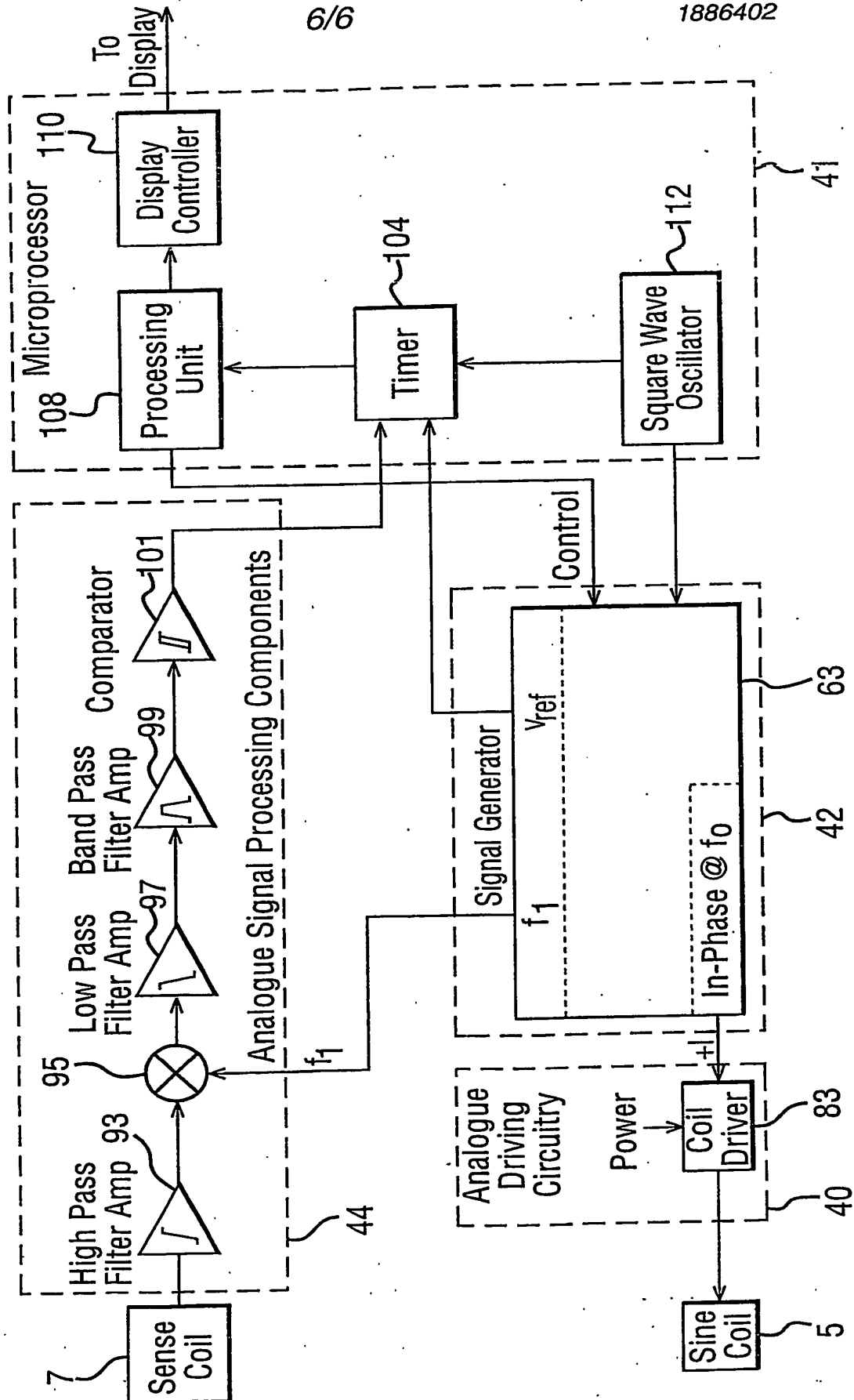


FIG. 7



PCT Application

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